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George C. Marshall Space Flight Center
Marshall Space Flight Center, Alabama 35812

SPECIFICATION: WELDING, ALUMINUM ALLOYS

PREPARED BY:

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SCIENCE AND ENGINEERING

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3/5/91 KB RELEASE

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WELDING ALUMINUM ALLOYS

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OUTLINE

SPECIFICATION: WELDING, ALUMINUM ALLOYS

1. SCOPE

1.1 Scope - This specification covers the welding and quality assurance requirements for manual and mechanized welding of aluminum and aluminum alloy materials for flight and support applications.

1.2 Classifications

1.2.1 Welding Processes - The following processes and any pulsed derivatives thereof are governed by this specification:

Gas Tungsten Arc Welding (GTAW)
Gas Metal Arc Welding (GMAW)
Variable Polarity Plasma Arc Welding (VPPAW)

1.2.2 Weld Classes - Welding performed using this specification shall be classified in accordance with the service of the weldments as follows. (Refer to Table I for a summary of Weld Class definition and requirements.)

1.2.2.1 Class I - (Flight or non-flight) welds shall meet the highest strength and quality requirements specified.

1.2.2.2 Class II - (Flight or non-flight) welds shall meet the strength and quality requirements specified and be construed as capable of sustaining a tensile load of 80% of a Class I weld.

1.2.2.3 Class III - (Non-flight only) structural welds shall meet the highest strength and quality requirements specified with the exception of internal quality requirements of section 3.10.

1.2.2.4 Class IV - (Non-flight only) structural welds shall meet the strength and quality requirements specified with the exception of internal quality requirements of section 3.xx, and be construed as capable of sustaining a tensile load of 80% of a Class I weld.

1.2.2.5 Class V - (Flight only) welds which are noncritical and non-structural and are contained so that failure will not affect other flight elements. These welds shall have no strength specified but shall meet the requirements specified in sections 3.1, 3.3.1, 3.5.1, and 3.6.2.

1.2.2.6 Class VI - (Non-flight only) welds which are noncritical, and non-structural shall have no strength specified but shall meet the quality requirements specified in section 3.6.2.

2. APPLICABLE DOCUMENTS

2.1 The following documents form a part of this specification to the extent specified herein. Unless otherwise indicated, the issue in effect on date of invitation for bids or request for proposals shall apply. When requirements in this specification and the requirements of any applicable document, conflict, the requirements identified in this specification shall take precedence.

2.1.1 Federal

BB-0925	Oxygen, Technical, Gas and Liquid
QQ-R-566	Rods, Welding, Aluminum and Aluminum Alloys

2.1.2 Military

MIL-STD-453	Inspection, Radiographic
MIL-STD-1595	Qualification of Aircraft, Missile, and Aerospace Fusion Welders
MIL-STD-6866	Inspection, Dye Penetrant
MIL-A-18455	Argon, Technical
MIL-E-16053	Electrodes, Welding, Bare, Aluminum Alloys
MIL-P-27407	Helium
MIL-H-6088	Heat Treatment of Aluminum Alloys

2.1.3 NASA

MSFC-STD-655	Standard, Weld Filler Material, Control of

2.1.4 American Welding Society

AWS A2.4	Symbols for Welding and Nondestructive Testing
AWS A3.0	Welding Terms and Definitions
AWS A5.10	Aluminum and Aluminum Alloy Bare Welding Rods and Electrodes
AWS A5.12	Tungsten Arc Welding Electrodes
AWS B2.1	Standard for Weld Procedure and Performance Qualification
AWS B4.0	Standard Methods for Mechanical Testing of Welds

AWS D1.2 Structural Welding Code - Aluminum

(Applications for copies should be addressed to American Welding Society, 2501 N.W. 7th Street, Miami, FL 33120)

2.1.5 American Society for Testing and Materials

ASTM E-8 Methods of Tension Testing of Metallic Materials

(Applications for copies should be addresses to American Society for Testing and Materials, 1916 Race Street, Philadelphia, PA 19103)

3. REQUIREMENTS

3.1 Equipment

3.1.1 Welding Equipment - Automatic, semiautomatic and machine welding shall be accomplished using equipment containing calibrated dials, meters, or recorders that indicate welding parameters. All welding equipment (including manual) shall be capable of producing welds that meet the requirements specified herein, when operated by a qualified operator in accordance with a qualified welding procedure specification where required.

3.1.1.1 Acceptance Testing - New, repaired, relocated, or modified welding machines shall be acceptance tested under the cognizance of the Quality Control Organization prior to release to manufacturing departments for production welding. Machines shall meet the requirements of the applicable purchase specification, design specification, or modification order. Power supplies and supporting components (electrical or mechanical or both) shall be capable of operating reliably within the range of parameters and duty cycle to be used for welding of production parts.

3.1.1.2 Calibration - Measuring instruments, meters, gages, or direct reading electrical control circuits to be utilized for automatic, semiautomatic, and machine welding operations shall be initially calibrated, and periodically recalibrated at intervals not to exceed six (6) months or when any maintenance is performed which may have changed calibration.

3.1.1.3 Maintenance and Records - Welding machines shall be provided with adequate periodic preventive maintenance service. A current record of each maintenance repair, or functional check shall be maintained for each welding machine. Records shall be located on welding machines.

3.1.2 Tooling and Fixtures - Tooling and fixtures used in the welding operation shall be constructed of non-magnetic materials that do not affect the welding arc, and are not detrimental to the weld quality. Tooling and fixtures shall not be a source of contamination of the weld or of the part being welded. Fixtures within two inches of the weld joint shall be visually free from rust, oxide scale, dirt, oil, grease, paint, low melting alloys (e.g. Pb, Sn, Cd) and other contaminants detrimental to weld quality.

3.2 Materials

3.2.1 Base Metals - Unless otherwise specified or approved by the procuring agency, the base metal shall be those alloys specified in Table II.

3.2.1.1 Base metal for qualification welding tests shall be identified by lot or heat number, type and condition, and shall maintain identification through all evaluation processes.

3.2.1.2 Base metal, material condition, and appropriate specification shall be recorded as a part of the weld procedure specification.

3.2.2 Filler Metals - Control of filler materials shall be in accordance with MSFC-STD-655. Unless otherwise specified or approved by the procuring agency, filler metal alloy shall be selected in accordance with Table II and shall conform to QQ-R-566 or MIL-E-16053 or AWS A.5.10. Weld filler metals and appropriate specification shall be recorded on the weld procedure specification.

3.2.3 Shielding Gas - Welding grade argon conforming to MIL-A-18455, helium conforming to MIL-P-27407, oxygen conforming to BB-0925, or a mixture of these gases shall be used for gas shielding. Shield gas mixtures shall be recorded as a part of the weld procedure specification.

3.2.4 Tungsten Electrodes - Tungsten electrodes shall conform to the requirements of AWS A5.12. The electrode

diameter, electrode tip shape, and alloy composition shall be recorded as a part of the weld procedure specification.

3.3 Weld Procedure and Performance Qualification

3.3.1 Welder Performance Qualification - Operators of automatic, semi-automatic, or manual welding equipment shall be qualified in accordance with MIL-STD-1595, latest revision. Operators may be qualified in accordance with other specifications which require qualification, on a case basis, when specifically approved by the procuring agency; (e.g. AWS D1.2, etc.).

3.3.2 Weld Procedure Specification - Prior to welding of the first production part of each different configuration of Class I and II welds, a qualification weld shall be made to establish a satisfactory welding procedure specification (WPS). Prior to first production of parts of Class III and IV welds, qualification welds shall be made to acceptable weld procedure specifications (WPS) in accordance with AWS B2.1. A suggested WPS form is illustrated in Figure 1. Weld procedure specification qualification may be performed in accordance with specifications other than those listed in this standard or as permitted by AWS B2.1, on a case basis, when specifically approved by the procuring agency; (e.g. AWS D1.2, etc.).

The qualification weld shall simulate the production part with respect to section thickness, alloy, heat treat condition, joint preparation, pre-weld cleaning, and fitup; and shall be made in either the actual production weld fixture or in a test fixture simulating the production fixture using the actual production welding equipment. The qualification weld shall be of sufficient length and width to provide the test specimens required by 3.3.3.

3.3.2.1 All machine welding parameters such as arc voltage, arc current, rate of travel and filler-wire feed rate shall be recorded during qualification welding. Manual weld parameters and operating parameter ranges shall be established during the schedule qualification.

3.3.2.2 The qualification weld shall be visually and nondestructively inspected as specified in 3.6.1. Following visual and nondestructive inspection, the qualification weld shall be subjected to the processes affecting mechanical properties to which the production part will be subjected, such as reinforcement removal, mechanical deformation and

thermal treatments associated with artificial aging, and stress relief.

3.3.2.3 Tolerances - For automatic, semiautomatic, and machine welding, welding parameter tolerances are to be listed in the qualified weld procedure specification. One or more test samples representing tolerance (s) extremes of the critical welding parameters (weld current, weld voltage, travel speed, and wire feed rate) shall be welded to verify acceptable welds, per paragraph 3.3.3.

3.3.2.4 Class I, II, and III welds shall be qualified in accordance with AWS B2.1, "Special Test weldments". Qualification welds shall simulate the production part with respect to section thickness, alloy heat-treatment, joint preparation, pre-weld cleaning, and fit-up; and shall be made in either the actual production fixture or in a test fixture simulating the production fixture using the production welding equipment. The qualification weld shall be of sufficient length and width to provide the test specimens required by 3.3.3.1, 3.3.3.2, and 3.3.3.3.

3.3.2.5 Class IV welds shall be qualified in accordance with AWS B2.1, "Standard Test Weldments".

3.3.2.6 Class V and VI welds with no specified strength requirements shall meet the quality requirements of section 3.6.2. (NOTE: No WPS is required.)

3.3.3 WPS Qualification - All test results, including nondestructive evaluation, shall be recorded on a Procedure Qualification Record (PQR) in accordance with the provisions of AWS B2.1. A suggested PQR form is illustrated in Figure 2.

3.3.3.1 Tensile Tests - For "special test weldments", (e.g. Class I, II, and III welded butt joints), a minimum of five specimens shall be tested for each qualification weld. For "standard test weldments", (e.g. Class IV welded butt joints), the number of tensile specimens to be tested for qualification of welds shall be per AWS B2.1. Tensile specimens and test procedures shall conform to ASTM-E-8. Tensile specimens shall be tested to destruction at room temperature. Percent elongation in 2.5 cm (1.0 inch) and/or 5 cm (2.0 inch) gauge lengths, yield, and ultimate tensile load shall be recorded. Weld strength shall meet or exceed the requirements of 3.7.1.

3.3.3.2 Shear Tests - For "special test weldments", a minimum of five specimens shall be tested for each qualification corner, T, Lap, and edge joint. When it is not feasible to fabricate shear test specimens from qualification welds, shear tests may be implemented in accordance with AWS B4.0 - Standard Method for Mechanical Testing of Welds. The shear strength shall meet or exceed the requirements of 3.7.2.

3.3.3.3 Metallographic Sections - For "standard and special test weldments", (e.g. Class I, II, III, and IV welds), the welded joint for each type specified (butt, corner, T, lap, edge) shall be sectioned transverse to the direction of welding and the surface adequately prepared for visual examination at a magnification of 10 X for fusion characteristics and weld defects. The section shall then be lightly etched to reveal microstructure and reexamined at a higher magnification. The section shall be examined for properties in accordance with paragraphs 3.6.3 and 3.10.

(a) Overall fusion of the weld, root penetration, burn-through, and blowholes
(b) Convexity, concavity, and size of bead or fillet
(c) Undercutting and overlapping
(d) Inclusions or voids
(e) Cracks

3.3.4 Records - Records of test specimens which meet the acceptance requirements of this specification for "special test weldments", or of AWS B2.1 for "Standard test weldments" shall be signed and dated by a qualified inspector, as an accurate record of the welding and testing of the procedure test weldment.

3.3.4.1 The welding procedure specification and procedure qualification record shall be prepared and retained as a permanent record in accordance with contract requirements. One copy of each shall be maintained at the welding station.

3.3.5 Welding Procedure Specification Approval - All welding procedure specifications and qualification records must be presented to MSFC for approval prior to use on flight hardware. The schedules must contain the welding parameters, identify the welding equipment and any pertinent information about the welding system used.

3.4 Preweld Operations

3.4.1 Joint Design - Joint design shall be in accordance with AWS D1.2 or the design drawing. Acceptable joints are butt, lap, corner, tee, and edge. Joints shall be documented on a weld procedure specification, design drawing, or other suitable document. The joint design should be selected primarily on the basis of load requirements.

3.4.2. Preweld Cleaning - Preweld cleaning of surfaces to be welded shall be accomplished in an environment which will not degrade the quality of the weld. The cleaned surfaces shall be maintained in an environment which is sufficiently controlled as to assure required quality welds. Filler materials and joints within two inches of the surfaces to be welded shall be free of oxide scale, dirt oil, grease, paint, low melting alloys (e.g. Pb, Sn, Cd), and other contaminants detrimental to weld quality. Cleanliness shall be maintained during welding.

3.4.3 Inspection - Prior to welding of each production part, a preweld inspection shall be performed in accordance with section 4.4.

3.5 Production Welding

3.5.1 Equipment Operational Check - A welding equipment operational readiness check shall be made immediately prior to a production weld to verify the equipment is operating properly.

3.5.2 Temperature Control - Preheat, interpass, and post heat temperatures shall be controlled so as not to degrade the properties of the material being welded. These parameters shall be recorded in an applicable weld procedure specification.

3.5.3 Tack Welding - Tack welding shall be allowed and shall become a part of the finished weld; (e.g. tack welds must be completely consumed by the final weldment). Tack welds shall be considered Class V welds. Upon completion of a finished weld, the tack areas shall be evaluated to the requirements of the finished weld.

3.5.4 Welding Technique

3.5.4.1 Class I, II, III, & IV Weld Joints - The technique of welding the initial passes from both sides where the weld roots overlap beneath the exposed surfaces (reference Figure 3A) shall not be allowed. Joints which have prepared grooves from one or both sides (reference Figure 3B and 3C) and or multi-pass welds shall have a weld land which is completely penetrated on the initial pass. Partial penetration welds from one side are permissible provided the opposite side is machined into the penetration root prior to completing the weld. Acceptable NDE procedures shall be employed to assure that the weld root has been exposed by machining. All penetration weld passes shall have no visual evidence of improper fusion or presence of dross. (These discrepancies can be readily detected by visual examination of the fracture plane after tensile tests of WPS qualification). Square groove welds shall be completely penetrated from one side (Reference Figure 3D).

3.5.4.2 Class V and VI Welded Joints - The technique of welding and joint geometry shall be as stated on the engineering drawing and/or as determined by the contractor. All partial penetration groove welds are Class V or VI.

3.5.5 Welding Procedure - Production welding shall be accomplished according to a qualified weld procedure specification. A specific weld procedure specification for each weld is required for production welding Class I and II welds whereas a weld procedure specification covering a range of thicknesses per AWS B2.1 guidelines is allowed for production welding Class III and IV welds.

3.5.6 Procedure Departure - Departure from the qualified welding procedure specification during production welding shall require withholding the part for Material Review Board disposition. The cause for departure shall be determined and corrective action taken prior to further production welding.

3.6 Postweld Operations

3.6.1 Inspection - Each completed weldment, and the base metal for 12.5 mm (0.5 inch) on either side of the weld edge, shall be inspected to assure compliance with the requirements of sections 3.6.2, 3.6.3, 3.9, 3.10, and as dictated by the class of weld.

3.6.2 General Workmanship Requirements - When employing visual inspection, weld deposits, buildup, and root reinforcement shall display a uniform appearance. The edge of the weld deposit shall blend into the base metal without unfused overlaps or undercut. The face and root sides shall be free of surface cracks, crater cracks, and other defects open to the surface. Except in the case of fillet welds, both the crown and the root reinforcement of the weldment shall be convex. The deposits shall be free of open voids or unfused overlapping folds.

3.6.3 Dimensional Requirements

3.6.3.1 Weld Appearance/Welds of Butt Joints - Welded butt joints shall have 100 % penetration and shall meet the geometry requirements of Figure 4 and Table III. The underbead width, including any runout, shall not exceed the maximum weld width specified in Table III. Undercutting, smooth concavity, lack of fill, or suckback shall be unacceptable in any weld where it occurs as a sharp notch or where the depth reduces the material thickness below the minimum thickness specified on the applicable drawing (Reference Figure 5).

3.6.3.1.1 Mismatch - Unless otherwise specified by drawing tolerances, the post-weld mismatch between two sheets or plates of a butt welded joint shall not exceed 0.508 mm (0.020 inch) for material thicknesses of 5.08 mm (0.200 inch) or less. For material thicknesses greater than 5.08 mm (0.200 inch), mismatch shall not exceed 10.16 mm (0.040 inch) or 10% of the material thickness (T), whichever is smaller.

3.6.3.1.2 Peaking - Peaking of the welded joint and adjacent base metal shall not exceed a total of 5 degrees as shown in Figure 6. When a weld will be subsequently intersected by another weld, peaking shall not exceed a total included angle of 2 degrees for the 15.2 cm (6 inches) of the weld adjacent to the weld intersection. A standard template or other device having specified reference points shall be used for determination of peaking.

3.6.3.1.3 Combination Mismatch and Peaking - The combined effect of mismatch and peaking on the efficiency of the weld joint are so related that one can be increased if the other is decreased. This condition can be tolerated if it can be shown by engineering analysis that positive margins of safety exist. The maximum permissible peaking and offset

allowed in this specification is voided if dimensional variations are beyond acceptable limits for proper assembly tolerances as specified on engineering drawings.

3.6.3.1.4 Weld Reinforcement Removal - Weld reinforcement, both face side and drop-through (root side), shall be removed when specified by the engineering drawing. The weld bead reinforcement may also be removed to eliminate defects occurring in the outer zones of the reinforcement unless otherwise specified on the engineering drawing. Such removal shall not thin the weld or parent metal below drawing dimensional requirements. When flush contour is required by the welding symbol, weld reinforcement or drop-through shall not exceed 0.015 inch. Metal removal shall be such that the reworked area shall blend smoothly with adjacent material without abrupt sectional changes. Surface roughness, after reinforcement removal, shall not exceed 250 microinches. Grinding of base metal is not permitted when wall thickness cannot be verified after grinding.

3.6.3.2 Fillet Welds - Continuous fillet welds including outside corner joints, lap joints and tee joints, shall have 100% penetration into the root of the joint (Reference Figure 7). Intermittent fillet welds shall have fusion of the root throughout the specified length. Unless otherwise specified on the engineering drawing, the fillet may be extended by 6 mm (0.25 inch) at each end without penetration in the extension. The minimum acceptable fillet size shall be that specified by engineering drawing. The maximum acceptable fillet size shall be the size specified plus 50 % or 4.8 mm (3/16 inch), whichever is the least, as permitted in section 3.9. The minimum acceptable actual throat shall equal or exceed the theoretical throat (Reference Figure 8). Fillet weld fusion of the root, (Reference Figure 7), shall be determined by evaluation of transverse sections taken from the qualification welds.

3.6.4 Weldment Straightening - Welds and adjacent base metal which have been deformed by the welding operation may be straightened; however, prior to implementation it shall be verified by nondestructive and destructive testing, and metallurgical evaluation that the process used for straightening shall not degrade the weld and surrounding material below specified design requirements. Following weldment straightening, the weld and adjacent base metal shall be inspected in accordance with section 3.6.1. Weldments in which defects have been revealed by such operations shall not be acceptable.

3.6.5 Post Weld Heat Treat Requirements - Weldments subject to heat treatment operations shall subsequently be inspected to the surface quality requirements of section 3.9.

3.7 Weld Joint Strength Requirements

3.7.1 Butt Joints - Class I and III welded butt joints shall meet the ultimate tensile strength requirements specified in Table IV or on the Engineering Drawings when tested in accordance with section 3.3.3.1. When dissimilar alloys are welded, the weld strength which pertains to the alloy having the lower tensile strength shall determine the minimum joint strength. Class II and IV welded butt joints shall meet 80 % of the Class I requirements.

3.7.2 Fillet Welds - Unless otherwise directed by the procuring agency, fillet weld shear ultimate strength shall meet 60 % of the ultimate tensile strength (Class I or II, whichever is applicable) requirements from Table IV. Where values are shown in Table IV for different thickness of the same temper, 60 % of the least value shall apply.

3.8 Repair Welding

3.8.1 Two additional welding operations may be permitted to correct any condition listed below provided the repair welding parameters and procedures are specified in a qualified repair weld procedure specification, and the repair is contained within the original weld zone.

Complete records of the repair welding operation, including identification of the repaired weldment, type of defect, and location of the repair weld shall be retained in permanent records.

(a) Undercut
(b) Lack of Fill
(c) Suckback
(d) Incomplete Penetration
(e) Crack and crack-like defects
(f) Oxides and Porosity
(g) Lack of Fusion

3.8.2 Material Review Board action is required when any one of the following conditions exist:

a) When more than two weld repair attempts have been performed on any one location.

b) When the wrong filler metal has been used.

c) When a weldment has been postweld heat-treated to increase the strength and cannot be returned to drawing requirements with additional heat treatments after reweld.

d) When finish machining has been completed prior to rewelding.

3.8.3 Reinspection of all repair weld areas shall be performed in accordance with section 3.6.1.

3.9 Weldment External Quality Requirements

3.9.1 External quality shall meet the following requirements, and shall apply to the final weld condition and to the face and root side of full penetration welds; and to the face side of partial penetration welds. Welds which are inaccessible for root side inspection shall be identified as such on engineering drawings and shall require approval for use by the procuring agency.

3.9.2 Welds which require 100 % penetration shall meet the reinforcement requirements of Figure 4.

3.9.3 Class I and III - Class I and Class III fusion welds shall meet the following surface quality requirements. Failure to meet any one requirement shall be cause for rejection.

3.9.3.1 Cracks - The weld metal and adjacent base metal shall contain no discernable cracks.

3.9.3.2 Improper Fusion - Incomplete penetration, laps or folds between the bead(s) and base metal shall be cause for rejection.

3.9.3.3 Close Spacing - Discontinuities that appear overlapping, touching or connected shall be treated as a single discontinuity.

3.9.3.4 Maximum Discontinuity Size - The maximum dimension of individual surface discontinuities, such as rounded porosity and oxides shall not exceed T/3 or 1.65 mm (0.065 inch) for butt welds, and S/3 or 1.27 mm (0.050 inch) for fillet welds, whichever is smaller for each weld.

3.9.3.5 Scattered Discontinuities - The sum of the areas of all individual surface discontinuities within any 2.5 cm (1 inch) of weld shall not exceed one-half the value of maximum discontinuity area from Figure 10. There shall be no more than fifteen individual surface discontinuities in any 2.5 cm (1 inch) of weld regardless of size or cumulative area.

3.9.3.6 Linear Discontinuities - Three or more discontinuities in a line are unacceptable if the line extends more than 6 mm (0.25 inch) and the discontinuities occupy more than 50 % of the length of the line.

3.9.3.7 Sharp Discontinuities - Sharp discontinuities shall be cause for rejection if the maximum dimension exceeds 2.54 mm (0.100 inch).

3.9.3.8 Cluster Discontinuities - Three or more discontinuities each measuring 0.254 mm (0.010 inch) or more, touching or falling within a 6 mm (0.25 inch) diameter circle, shall be classified as a cluster when the sum of their maximum dimension exceeds T/3 or 1.65 mm (0.065 inch) for butt welds, and S/3 or 1.27 mm (0.050 inch) for fillet welds, whichever is smaller for each weld. Two clusters are unacceptable if separated by less than butt weld thickness (T) or less than specified fillet size (S).

3.9.4 Classes II and IV - Class II and Class IV welds shall meet the surface quality requirements of 3.9.3.1, 3.9.3.2, and 3.9.3.3 and the following paragraphs. Failure to meet any one requirement shall be cause for rejection.

3.9.4.1 Maximum Discontinuity Size - Individual surface discontinuities such as rounded porosity and oxides, whose maximum dimension exceeds T/2 or 2.54 mm (0.100 inch) for butt joints and S/3 or 1.90 mm (0.075 inch) for fillet welds, whichever is smaller for each weld, shall be cause for rejection.

3.9.4.2 Scattered Discontinuities - The sum of the areas of all individual surface discontinuities within any 2.5 cm (1 inch) of weld shall not exceed the value for the maximum discontinuity area from Figure 10.

3.9.4.3 Linear Discontinuities - Three or more discontinuities which are grouped in a line are unacceptable if the line extends more than 12.5 mm (0.500 inch) and the discontinuities occupy more than 50 % of the length of the line.

3.9.4.4 Sharp Discontinuities - Sharp discontinuities viewed on the weldment surface shall be cause for rejection if the maximum dimension exceeds 2.54 mm (0.100 inch).

3.9.4.5 Cluster Discontinuities - Three or more discontinuities, each measuring 0.508 mm (0.020 inch) or more, touching or falling within a 10 mm (0.25 inch) diameter circle, shall be classified as a cluster when the sum of their dimension exceeds T/3 or 1.65 mm (0.065 inch) for butt welds, and S/3 or 1.27 mm (0.050 inch) for fillet welds, whichever is smaller for each weld. Two clusters are unacceptable if separated by less than half the butt weld material thickness (T/2) or by less than half the fillet weld specified size (S/2).

3.9.5 Class V and VI - Class V and VI welds shall meet the general workmanship requirements of section 3.6.2.

3.10 Weldment Internal Quality Requirements

3.10.1 Internal quality requirements of fusion welds shall be consistent with the weld class requirements specified by design documentation. The weld quality requirements may be varied from that specified provided that it can be shown by engineering analysis (e.g. stress and fracture mechanics analysis) and verified by mechanical testing that the resulting structural properties are adequate for intended applications. Variations from the requirements of this specification, plus the supporting test data and rationale, must be approved by the procuring agency.

NOTE: Nondestructive inspection per section 4.5.3 may be waived for fillet welds when the specified fillet size is increased 25 % for Class I welds or 20 % for Class II and Class III welds given prior Engineering Design approval.

3.10.2 Class I - Class I fusion welds shall meet the following internal quality requirements. Failure to meet any one of the following requirements shall be cause for rejection.

3.10.2.1 Cracks - The weld metal and adjacent base metal shall not contain any discernable cracks. The line at the root of the weld (Figure 7) for fillet welds shall not be considered to be a crack.

3.10.2.2 Improper Fusion/Incomplete Penetration - Improper fusion, incomplete penetration, laps and/or folds between the base metal and weld, or between weld beads or multiple pass groove welds shall be unacceptable.

3.10.2.3 Close Spacing - Discontinuities that appear overlapping, touching or connected viewed normal to the weld surface for butt welds, and at an optimum angle for fillet welds shall be treated as a single discontinuity. The spacing requirement is not applicable to discontinuities connected to the root of weld (Figure 7) for fillet welds. (Optimum angle is defined as the angle nearest to the normal view, considering geometry constraints which prevent access of x-ray equipment).

3.10.2.4. Maximum Discontinuity Size - The maximum dimension of an individual internal discontinuity (voids and inclusions) as viewed normal to the weld surface for butt welds, and at an optimum angle for fillet welds shall not exceed the values obtained from Figure 9.

3.10.2.5 Scattered Discontinuities - Scattered internal discontinuities not exceeding individual discontinuity limitations shall be evaluated for accumulative area per 2.5 cm (1 inch) of weld. Area calculations shall be based on the best fit circle or rectangle. Butt and fillet welds, including discontinuities connected to the root of fillet welds (Figure 7), shall conform to the requirements of Figure 10 and butt welds shall also conform to the following:

a) Any 2.5 cm (1 inch) of weld with maximum allowable area of Figure 10 shall have no more than one-half the maximum allowable area in each adjacent 2.5 cm (1 inch) of weld.

b) That 15.2 cm (6 inches), i.e. 7.6 cm (3 inches) to each side of the intersection, of weld intersection by another weld shall have the maximum allowable area of Figure 10 reduced by one-third.

c) There shall be no more than 15 discontinuities in any 2.5 cm (1 inch) of weld regardless of size or cumulative area loss.

3.10.2.6 Linear Discontinuities - Three or more discontinuities which are in line are unacceptable in the line extends more than 6 mm (0.25 inch) and the discontinuities occupy more than 50 % of the length of the line. This requirement is not applicable to discontinuities connected to the root of fillet welds (Figure 7).

3.10.2.7 Sharp Discontinuities - Any discontinuity that appears to have a crack-like extension shall be cause for rejection. If the longest accumulative dimension is more than five times the width at the smallest dimension, the indication shall be cause for rejection. This requirement is not applicable to discontinuities connected to the root of fillet welds (Figure 7).

3.10.2.8 Cluster Discontinuities - Three or more discontinuities, each measuring 0.254 mm (0.010 inch) or more, touching or falling within a 6 mm (0.25 inch) diameter circle shall be classified as a cluster when the sum of their dimensions exceeds the allowable maximum dimension of an individual discontinuity (Figure 9). For butt welds, two clusters are unacceptable if separated by less than T. For fillet welds, two clusters are unacceptable if separated by less than the specified fillet sizes. This requirement is not applicable to discontinuities connected to the root of fillet welds (Figure 7).

3.10.3 Class II - Internal quality of Class II fusion welds shall meet the requirements of 3.10.2.1, 3.10.2.2, and 3.10.2.3, and the following paragraphs. Failure to meet any of the requirements shall be cause for rejection.

NOTE: One hundred percent (100%) radiographic inspection of Class II welds may be relaxed at the discretion of the procuring agency, upon demonstration and certification of acceptable quality performance and after approval of a radiographic sampling plan.

3.10.3.1 Maximum Discontinuity Size - The maximum dimension of an individual internal discontinuity (void and/or inclusions) as viewed normal to the weld surface for butt welds, and at an optimum angle for fillet welds shall not exceed the value obtained from Figure 9.

3.10.3.2 Scattered Discontinuities - Scattered internal discontinuities not exceeding the individual discontinuity limitations shall be evaluated for accumulative area per 2.5 cm (1 inch) of weld. In addition, all discontinuities connected to the root of a fillet weld (Figure 7) shall be included in the accumulative area. Area calculations shall be based on the best fit circle or rectangle. The area in any 2.5 cm (1 inch) of weld shall not exceed the value obtained from Figure 10.

3.10.3.3 Linear Discontinuities - Three or more discontinuities which are in a line are unacceptable if the line extends more than 12.5 mm (0.5 inch) and the discontinuities occupy more than 50 % of the length of the line. This requirement is not applicable to discontinuities connected to the root of fillet welds (Figure 7).

3.10.3.4 Sharp Discontinuities - Any discontinuity which appears to have a crack-like extension shall be cause for rejection. If the longest accumulative dimension is more than seven times the width at the smallest dimension the discontinuity shall be cause for rejection. This requirement is not applicable to discontinuities connected to the root of fillet welds (Figure 7).

3.10.3.5 Cluster Discontinuities - Three or more discontinuities, each measuring 0.508 mm (0.020 inch) or more, touching or falling within a 6 mm (0.250 inch) diameter circle shall be classified as a cluster when the sum of their maximum dimensions exceeds the allowable maximum dimension of an individual discontinuity (Figure 9). For butt welds, two clusters are unacceptable if separated by less than half the material thickness (T/2). For fillet welds, two clusters are unacceptable if separated by less than half the specified fillet size (S/2). This requirement is not applicable to discontinuities connected to the root of fillet welds (Figure 7).

4.0 QUALITY ASSURANCE

4.1 The supplier is responsible for the performance of all inspection requirements as specified herein. Except as otherwise specified, the supplier may utilize his own or any other inspection facilities and services acceptable to and approved by the procuring agency. Inspection and test records shall be kept complete and upon request, made available to the procuring agency, or its designated

representative. The procuring agency or its designated representative reserves the right to perform any or all of the inspections set forth in the specification to ensure that the end item conforms to the prescribed requirements.

4.2 Nondestructive testing procedures to be employed in inspection for weldment internal and surface quality requirements shall be qualified/validated as being capable of detecting the weldment quality criteria prescribed, prior to inspection of the first production weld. The documentation proof of capability shall be retained as a permanent record.

4.3 Joint Design and WPS Quality Assurance - The quality engineer shall assure that the joint design meets the requirements of 3.4.1, and that the WPS meets the requirements of 3.3.2.

4.4 Preweld and Weld Inspection

4.4.1 Documentation relative to the production weld shall be inspected for conformance with section 3.

4.4.2 Filler metal shall be examined for conformance to section 3.2.2, and the qualified weld procedure specification.

4.4.3 Inert shielding gas shall be examined for conformance to section 3.2.3 and the qualified weld procedure specification.

4.4.4 Weld joints and tooling shall be inspected for conformance to sections 3.1.2 and 3.4.1.

4.4.5 Welding equipment shall be inspected for conformance of equipment settings to the qualified weld procedure specification. Refer to section 3.1.

4.4.6 Quality assurance shall certify that each production weld was made within the range of operating parameters established in the WPS. All departures shall be noted and referred to the MRB for disposition.

4.5 Post Weld Inspection

4.5.1 Visual Inspection - The weld metal and adjacent base metal shall be visually inspected to assure compliance with the requirements of section 3.6.2. The weld shall be

in the as-welded condition for the initial inspection, except that surface smut and loose oxide shall have been removed.

4.5.2 Dimensional Inspection - Dimensional inspection shall be performed on Class I, II, III, IV, V and VI welds to assure compliance with the requirements of section 3.6.3.

4.5.3 Internal Quality Inspection - Nondestructive inspection shall be performed to assure compliance with the internal quality requirements of section 3.10. Radiographic technique is the preferred inspection method; however, other techniques may be used in lieu of radiography if approved by the procuring agency.

4.5.3.1 Nondestructive inspection procedures employing the following techniques shall be qualified in accordance with the requirements of section 4.2, and shall meet the cited criteria.

Radiography: MIL-STD-453

4.5.3.2 A three to seven power optical magnifier shall be used as an aid in examination of radiographs to afford closer examination of suspect areas and to determine image dimensions.

4.5.3.3 When reliability of inspection and critical flaw detection so dictate, redundant and/or complementing inspection techniques and procedures shall be employed.

NOTE: One hundred per cent (100%) radiographic inspection of welds may be relaxed at the discretion of the procuring agency, upon demonstration and certification of acceptable quality performance and after approval of a radiographic sampling plan.

4.5.4 Surface Quality Inspection - Nondestructive inspection shall be performed to assure compliance with the surface quality requirements of section 3.9. Penetrant technique is the preferred inspection method; however, other techniques may be used in lieu of penetrant if approved by the procuring agency.

4.5.4.1 Nondestructive inspection procedures employing the following technique shall be qualified in accordance with the requirements of section 4.2, and shall meet the cited

criteria.

Dye Penetrant: MIL-STD-6866

4.5.4.2 When reliability of inspection and critical flaw detection so dictate, redundant and/or complementing inspection techniques and procedures shall be employed.

4.5.4.3 Weldments which are machined, ground, or otherwise mechanically worked, causing disruption or smearing of the material surface, shall be etched to remove the masking material, prior to penetrant application. Removal of 0.0004 inches of aluminum material by etching generally assures smeared material removal.

4.5.4.4 For penetrant inspection of unshaved VPPA weld root beads, transverse indications confined to the width of the weld bead are acceptable except at weld intersections. Transverse indications extending into the parent material or the toe radius are to be rejected regardless of length.

4.5.5 Records - A continuous audit of weldment production quality shall be maintained. Resulting records shall include the location of repairs, type of defects repaired, procedures used, and inches of repair per total inches of weld. These records shall be summarily accounted on a quarterly basis, with such accounting made available to the procuring agency upon request.

5.0 NOTES

5.1 Intended Use - Weld quideline and acceptance criteria for aerospace flight equipment and ground support equipment.

5.2 Ordering Data - Procurement documents should specify the title, number and date of this specification.

5.3 Definitions - Definitions pertaining to welding as used herein conform to the standard definitions of AWS A3.0 and the following paragraphs.

5.3.1 Material Thickness - The minimum material thickness of the thinnest joint member per drawing tolerance is designated "t".

5.3.2 Weld Intersection - As used herein, the term weld intersection refers to the meeting of two (or more) welds at

a point where the second weld may or may not completely cross the first weld.

5.3.3 Welder Performance Qualification - The demonstration of a welder's ability to produce welds meeting prescribed standards.

5.3.4 Weld Procedure Specification (WPS) - A document providing in detail the required variables for a specific application to assure repeatability by properly trained welders and welding operators.

5.3.5 Special Test Weldments - A "special test weldment" is a test weldment which is evaluated for procedure qualification by performing tests specified by a referencing document or procuring agency. Types of special test weldments are described in AWS B2.1.

5.3.6 Standard Test Weldments - A "standard test weldment" is a test weldment which is evaluated for procedure qualification by performing specific tests. The specific tests; and the type, number, and location of the required test specimens for procedure qualification are provided in AWS B2.1.

5.3.7 Procedure Qualification Record (PQR) - A document providing the actual welding variables used to produce an acceptable test weld and the results of tests conducted on the weld for the purpose of qualifying a welding procedure specification.

5.3.8 Qualified Inspector - A certified individual with the responsibility and ability to judge the quality of the welded specimens in relation to some form of written specification. In this instance the specification shall be the WPS.

5.3.9 Optimum Angle - Optimum angle is defined as the angle nearest to the normal view, considering geometry constraints which prevent access of x-ray equipment.

5.4 Symbols

5.4.1 Welding Symbols - The standard welding and nondestructive testing symbols that are accepted for designation on drawings are listed in AWS A2.4.

5.5 Changes

5.5.1 Requests for deviation from, or waiver of, applicable paragraphs of this specification should be directed to the procuring agency and to the Materials and Processes Laboratory, Marshall Space Flight Center, Huntsville, Alabama, 35812; together with supporting information.

NOTICE: When government drawings, specifications, or other data are used for any purpose other than in connection with a definitely related Government procurement operation, the United States Government thereby incurs no responsibility nor any obligation whatsoever; and the fact that the Government may have formulated, furnished, or in any way supplied the said drawings, specifications, or other data is not to be regarded by implication or otherwise as in any manner licensing the holder or any other person or corporation, or conveying any rights or permission to manufacture, use, or sell any patented invention that may in any way be related thereto.

TABLE I
WELD CLASS DEFINITION AND REQUIREMENTS

CLASS / REQUIREMENTS	FLIGHT/ NON-FLIGHT STRUCTURAL		NON-FLIGHT STRUCTURAL		FLIGHT NON-STRUCTURAL	NON-FLIGHT NON-STRUCTURAL
	1	2	3	4	5	6
100% STRENGTH	✳		✳			
80% STRENGTH		✳		✳		
INTERNAL QUALITY REQUIREMENTS	✳	✳				
EXTERNAL (1) QUALITY REQUIREMENTS (2)	✳	✳	✳	✳	✳	✳

NOTE: (1) APPLIES TO FACE AND ROOT OF WELD

(2) WELDS INACCESSIBLE FOR ROOT SIDE INSPECTION SHALL REQUIRE APPROVAL FOR USE BY THE PROCURING AGENCY.

TABLE II
FILLER ALLOYS APPLICABLE FOR WELDING ALUMINUM ALLOYS AND COMBINATIONS

BASE ALUMINUM ALLOY	2014	2219	5052	6061*	5456
2014	4043 2319				
2219	2319 4043	2319			
5052			5356		
6061*	4043	4043	4043	4043	
5456	4043 5356	4043 5356	5356 5556	4043 5356	5356 5556

* FILLER METAL SHALL ALWAYS BE USED WHEN WELDING 6061.

TABLE III
DIMENSIONAL REQUIREMENTS FOR BUTT WELDS

THICKNESS		d-MINIMUM		AS WELDED REINFORCEMENT MIMINUM				WELD WIDTH W & W' MAXIMUM	
				R		R'		MULTIPASS BEVELED JOINT AND TORCH OSCILLATED	SINGLE PASS SQUARE BUTT
mm	in	mm	in	mm	in	mm	in		
3	<1/8	0.508	0.020	0.127	0.005	0.381	0.015	5T	9.5mm (3/8 in) or 5T WHICHEVER IS SMALLER
3-6	1/8-1/4	1.270	0.050	0.127	0.005	0.381	0.015	1T + 10.2 mm (0.4 in)	1T + 6 mm (1/4 in)
6	>1/4	1.524	0.060	0.127	0.005	0.381	0.015	AS REQUIRED BY DESIGN	AS REQUIRED BY JOINT DESIGN

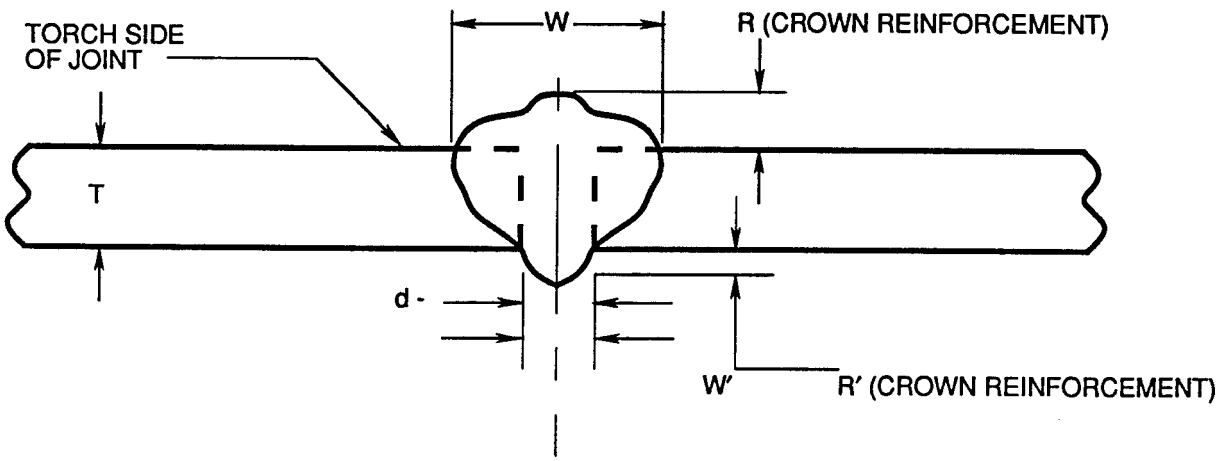


FIGURE 4

NOTE

d = DISTANCE FROM ORIGINAL JOINT CENTERLINE TO EDGE OF ROOT REINFORCEMENT. EXAMINE IN THE AS-WELDED CONDITION TO ENSURE THAT THE ORIGINAL JOINT CENTERLINE CAN BE DETECTED ON THE ROOT SIDE OF THE JOINT.

TABLE IV
BUTT WELD ULTIMATE TENSILE STRENGTH REQUIREMENTS

ALLOY	TEMPER OF BASE MAT'L DURING WELD OPERATION	POST WELD AGE CYCLE	THICKNESS OF THINNER MEMBER OF WELD JOINT		ULTIMATE TENSILE STRENGTH			
					AVERAGE		MIN SINGLE VALUE	
			mm	inch	Nx103/ cm^2	KSI	Nx103/ cm^2	KSI
2014	T6	AS WELDED	<3 3-6 >6	<1/8 1/8-1/4 >1/4	31.4 29.3 27.9	45.5 42.5 40.5	29.7 27.6 26.2	43 40 38
2219	T81 T87 T3X*	AS WELDED AS WELDED 350 °F (177 °C) FOR 18 HRS.	ALL ALL TO 6 >6-13 >13-19 >19-25 >25-32 >32-38	ALL ALL TO 1/4 >1/4-1/2 >1/2-3/4 >3/4-1 >1-1 1/4 >1 1/4-1 1/2	27.6 27.6 30.3 29.0 30.3 31.0 31.7 32.4	40 40 44 42 44 45 46 47	26.2 26.2 29.9 27.6 29.0 29.7 30.3 31.0	38 38 42 40 42 43 44 45
5052	ALL	AS WELDED	ALL	ALL	19.3	28	17.2	25
5456	ALL	AS WELDED	ALL	ALL	30.3	44	29.0	42
6061	T4 T6	AS WELDED AS WELDED	ALL ALL	ALL ALL	18.6 18.6	27 27	16.6 16.6	24 24

AVERAGE SHALL BE THE ARITHMETIC AVERAGE OF ALL VALUES MEASURED AND NO SINGLE VALUE SHALL BE LESS THAN THE MINIMUM SINGLE VALUE SPECIFIED.

* APPLICABLE TO TEMPERS WHICH REQUIRE AN AGING CYCLE OF 177 °C ± 5 °C (350 °F ± 10 °F) FOR 18 HOURS PER MIL-H-6088. BUTT WELD ULTIMATE TENSILE STRENGTH REQUIREMEMTS FOR TEMPERS WHICH REQUIRE OTHER POST WELD AGING CYCLES MUST BE APPROVED BY THE PROCURING AGENCY.

SUGGESTED
WELDING PROCEDURE SPECIFICATION (WPS)

Identification _____

Date _____ Revision _____

Company name _____

Support PQR no. (s) _____ Type — Manual ( ) Semiautomatic ( )

Welding process(es) _____ Machine ( ) Automatic ( )

Backing: Yes ( ) No ( )

Backing material (type) _____

Material number _____ Group ____ To material number _____ Group _____

Material spec. type and grade _____ To material spec. type and grade _____

Base metal thickness range: Groove _____ Fillet _____

Deposited weld metal thickness range _____

Filler metal F no. _____ A no. _____

Spec. no. (AWS) _____ Flux trade name _____

Electrode-flux (Class) _____ Type _____

Consumable insert: Yes ( ) No ( ) Classifications _____

_____ Shape _____

Position(s) of joint _____ Size _____

Welding progression: Up ( ) Down ( ) Ferrite number (when reqd.) _____

PREHEAT: **GAS**

Preheat temp., min. _____ Shielding gas (es) _____

Interpass temp., max. _____ Percent composition _____

(continuous or special heating, where applicable, should be recorded) Flow rate _____

Root shielding gas _____

POSTWELD HEAT TREATMENT: Trailing gas composition _____

Temperature range _____ Trailing gas flow rate _____

Time range _____

Tungsten electrode, type and size _____

Mode of metal transfer for GMAW: Short-circuiting ( ) Globular ( ) Spray ( )

Electrode wire feed speed range: _____

Stringer bead Weave bead ( ) Peening: Yes ( ) No ( )

Oscillation _____

Standoff distance

Multiple ( ) or single electrode ( )

Other _____

Weld layer(s)	Process	Filler metal Class	Filler metal Dia.	Current Type & polarity	Current Amp range	Current Volt range	Travel speed range	
								e.g., Remarks, comments, hot wire addition, technique, torch angle, etc.

Approved For Production by _____

Employer

Note: Those items that are not applicable should be marked N.A.

FIGURE 1

5-11448-0-299

SUGGESTED
PROCEDURE QUALIFICATION RECORD (PQR)

WPS no. used for test _____ Welding process (es) _____

Company _____ Equipment type and model (sw) _____

JOINT DESIGN USED (2.6.1)

Single ( ) Double weld ( )

Backing material _____

Root opening _____ Root face dimension _____

Groove angle _____ Radius (J-U) _____

Back gouging: Yes ( ) No ( ) Method _____

BASE METALS (2.6.2)

Material spec. _____ To _____

Type or grade _____ To _____

Material no. _____ To material no. _____

Group no. _____ To group no. _____

Thickness _____

Diameter (pipe) _____

Surfacing: Material _____ Thickness _____

Chemical composition _____

Other _____

FILLED METALS (2.6.3)

Weld metal analysis A no. _____

Filler metal F no. _____

AWS specification _____

AWS classification _____

Flux class _____ Flux brand _____

Consumable insert: Spec. _____ Class. _____

Supplemental filler metal spec. _____ Class. _____

Non-classified filler metals _____

Consumable guide (ESW) Yes ( ) No ( )

Supplemental deoxidant (EBW) _____

POSITION (2.6.4)

Position of groove _____ Fillet _____

Vertical progression: Up ( ) Down ( )

PREHEAT (2.6.5)

Preheat temp., actual min. _____

Interpass temp., actual max. _____

WELD INCREMENT SCHEDULE

POSTWELD HEAT TREATMENT (2.6.6):

Temp. _____

Time _____

Other _____

GAS (2.6.7)

Gas type (s) _____

Gas mixture percentage _____

Flow rate _____

Backing gas _____ Flow rate _____

Root shielding gas _____

EBW vacuum ( ) Absolute pressure ( )

ELECTRICAL CHARACTERISTICS (2.6.8)

Electrode extension _____

Standoff distance _____

Transfer mode (GMAW) _____

Electrode diameter tungsten _____

Type tungsten electrode _____

Current: AC ( ) DCEP ( ) DCEN ( ) Pulsed ( )

Heat input _____

EBW: beam focus current _____ Pulse freq. _____

Filament type _____ Shape _____ Size _____

Other _____

TECHNIQUE (2.6.9)

Oscillation frequency _____ Weave width _____

Dwell time _____

String or weave bead _____ Weave width _____

Multi-pass or single pass (per side) _____

Number of electrodes _____

Peening _____

Electrode spacing _____

Arc timing (SW) _____ Lift ( )

PAW: Conventional ( ) Keyhole ( )

Interpass cleaning:

Pass no.	Filler metal size	Amps	Volts	Travel speed (ipm)	Filler metal wire (ipm)	Slope induction	Special notes (process, etc.)

Note: Those items that are not applicable should be marked N.A.

FIGURE 2A

TENSILE TEST SPECIMENS: SUGGESTED PROCEDURE QUALIFICATION RECORD

PQR No.

Type: _____ Tensile specimen size: _____ Area: _____

Groove ( ) Reinforcing bar ( ) Stud welds ( )

Tensile test results: (Minimum required UTS _____ psi)

Specimen no.	Width, in.	Thickness, in.	Area, in. ^{2}	Max load lbs	UTS, psi	Type failure and location

GUIDE BEND TEST SPECIMENS – SPECIMEN SIZE: _____

Type	Result	Type	Result

MACROEXAMINATION RESULTS: Reinforcing bar ( ) Stud ( )

1. _____ 4. _____
2. _____ 5. _____
3. _____

SHEAR TEST RESULTS – FILLETS:

1. _____ 3. _____
2. _____ 4. _____

IMPACT TEST SPECIMENS

Type: _____ Size: _____

Test temperature _____

Specimen location: WM = weld metal; BM = base metal; HAZ = heat-affected zone

Test results:

Welding position	Specimen location	Energy absorbed (ft.-lbs)	Ductile fracture area (percent)	Lateral expansion (mils)

IF APPLICABLE	RESULTS	
Hardness tests: ( ) Values _____	Acceptable ( )	Unacceptable ( )
Visual (special weldments 2.4.2) ( )	Acceptable ( )	Unacceptable ( )
Torque ( ) psi	Acceptable ( )	Unacceptable ( )
Proof test ( ) Method _____	Acceptable ( )	Unacceptable ( )
Chemical analysis ( )	Acceptable ( )	Unacceptable ( )
Non-destructive exam ( ) Process _____	Acceptable ( )	Unacceptable ( )
Other _____	Acceptable ( )	Unacceptable ( )

Mechanical Testing by (Company) _____ Lab No. _____

We certify that the statements in this Record are correct and that the test welds are prepared, welded, and tested in accordance with the requirements of the American Welding Society Standard for Welding Procedure and Performance Qualification (AWS B2.1-83).

Qualifier: _____ Reviewed by: _____

Date: _____ Approved by: _____

Employer

FIGURE 2B

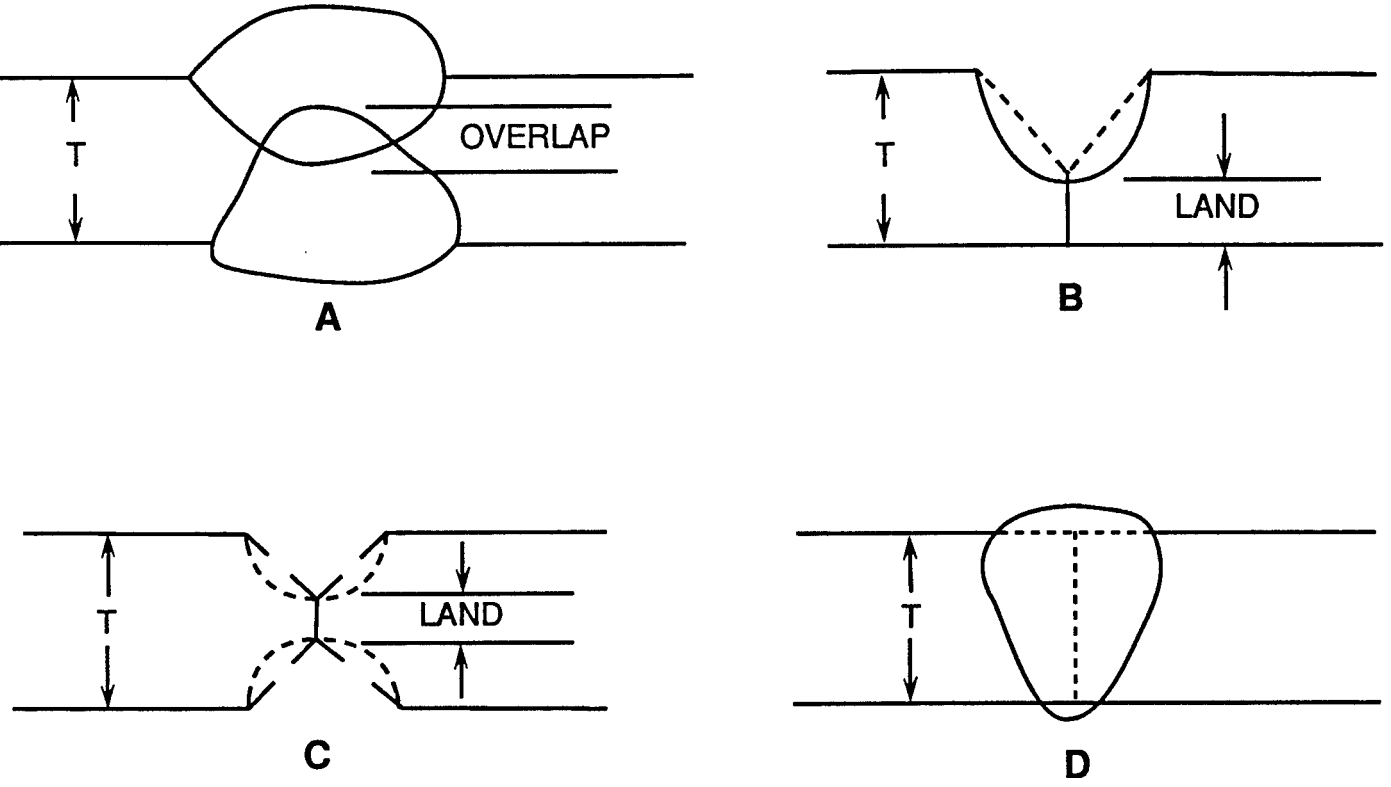


FIGURE 3
WELD TECHNIQUE REQUIREMENTS PER 3.5.4.1

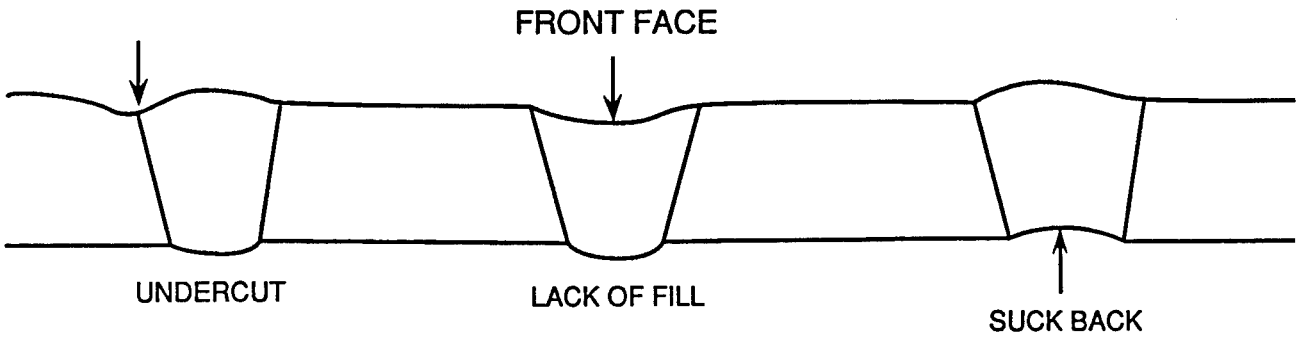


FIGURE 5
UNACCEPTABLE CONDITIONS PER 3.6.3.1

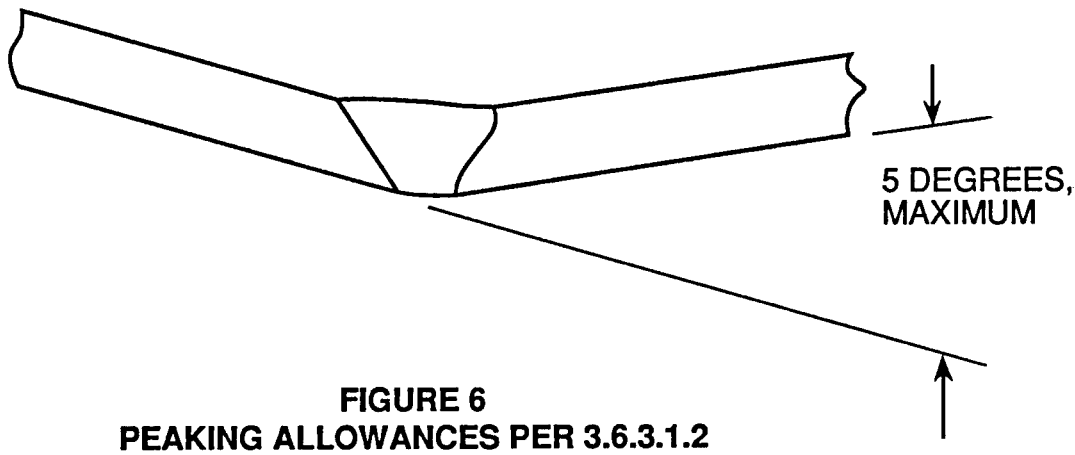
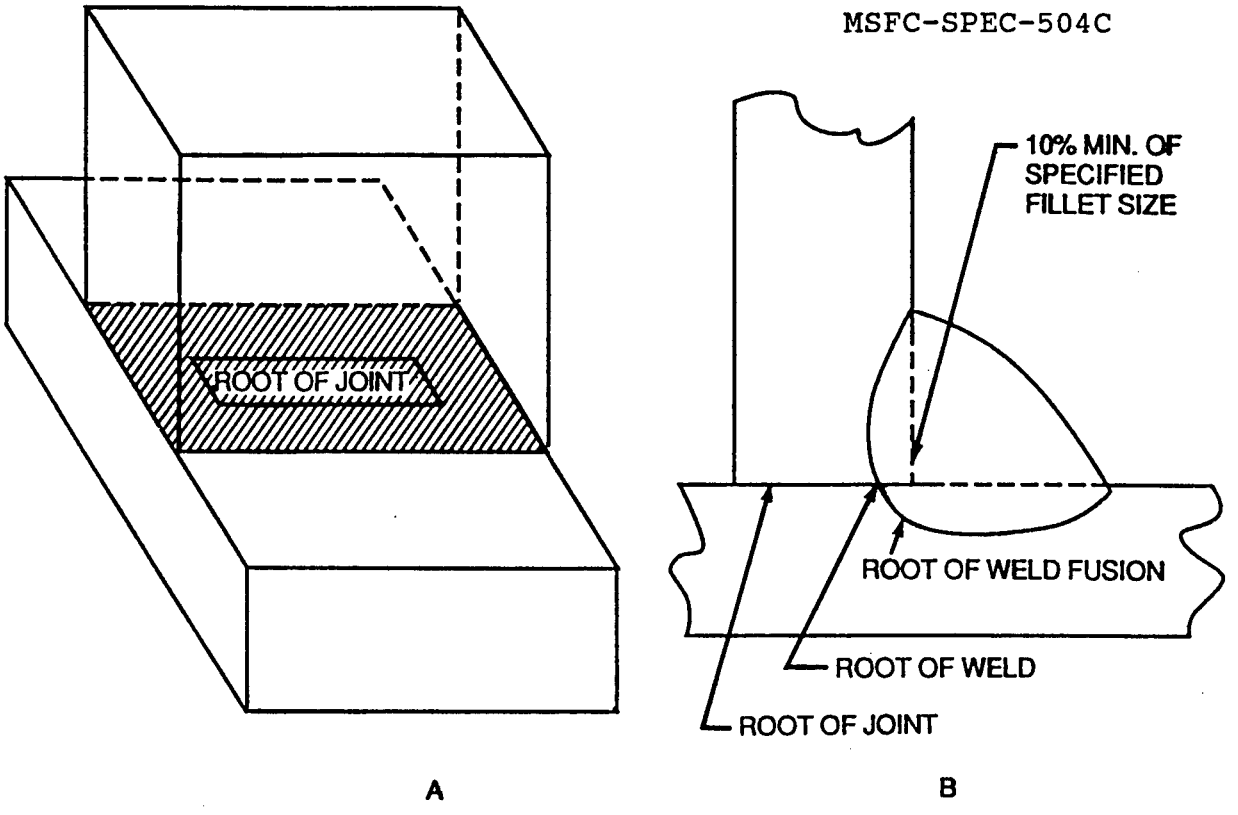


FIGURE 6
PEAKING ALLOWANCES PER 3.6.3.1.2

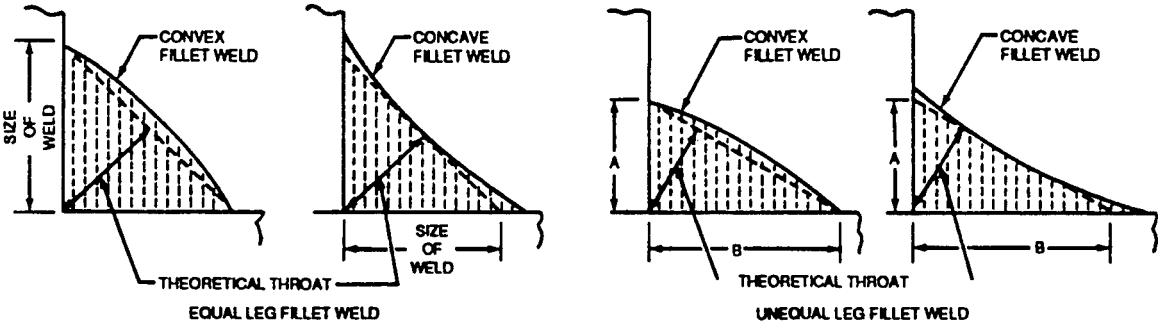


NOTES: ROOT OF JOINT – THAT PORTION OF A JOINT WHERE MEMBERS ARE CLOSEST TO EACH OTHER.

ROOT OF WELD – THE POINT, AS SHOWN IN CROSS SECTION, AT WHICH THE WELD INTERSECTS THE BASE METAL SURFACES.

THE ROOT OF THE WELD SHALL PENETRATE TO THE EXTENT THAT THE ACTUAL THROAT DIMENSION EXCEEDS THE THEORETICAL THROAT DIMENSION. IN ADDITION, EACH MEMBER SHALL BE PENETRATED A MINIMUM OF 10% OF THE SPECIFIED FILLET SIZE AT THE ROOT OF THE WELD. EACH LEG LENGTH SHALL SHOW FUSION ALONG THE SURFACE OF EACH COMMON MEMBER.

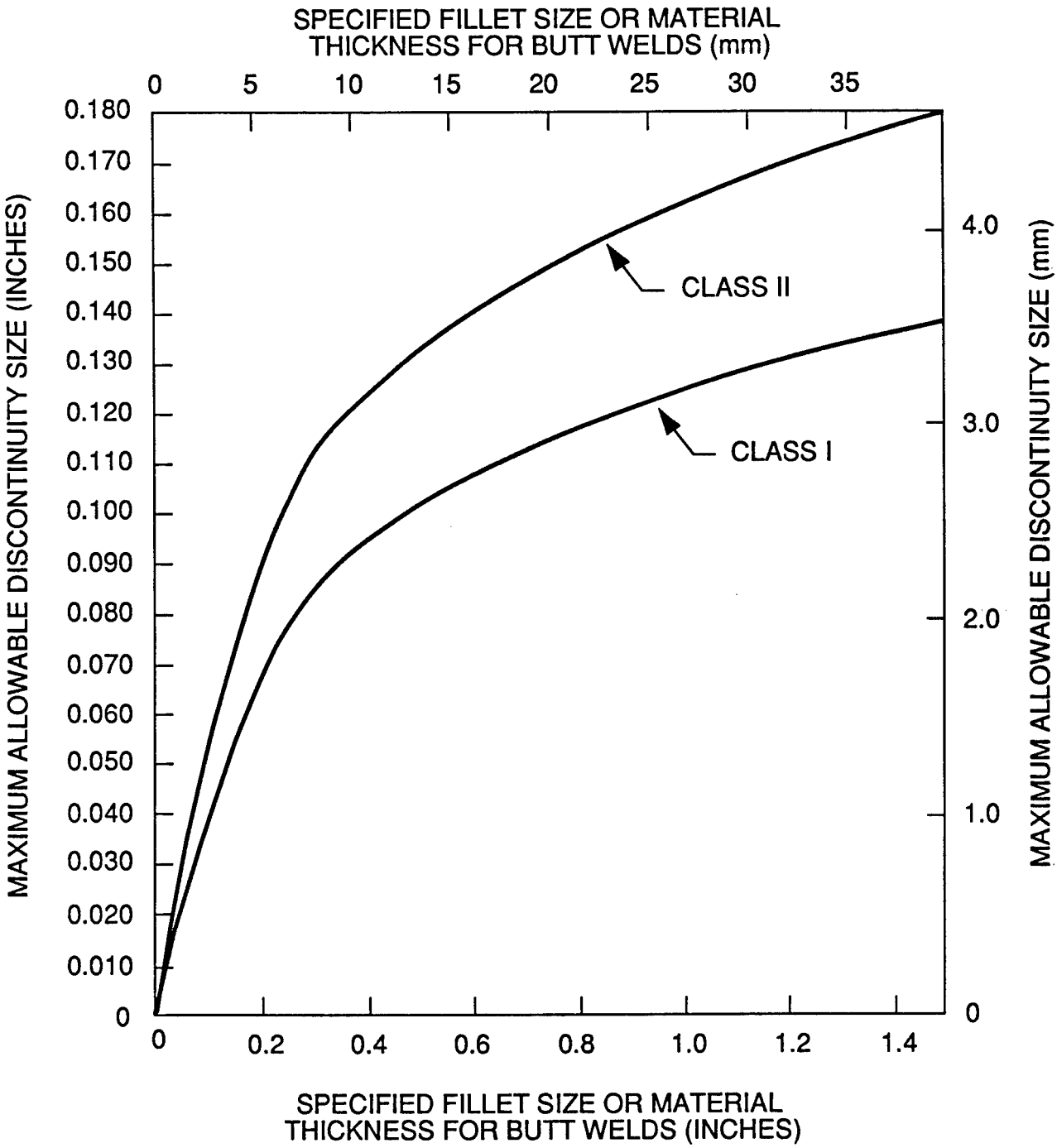
FIGURE 7
ROOT OF JOINT AND WELD, REFERENCE 3.6.3.2



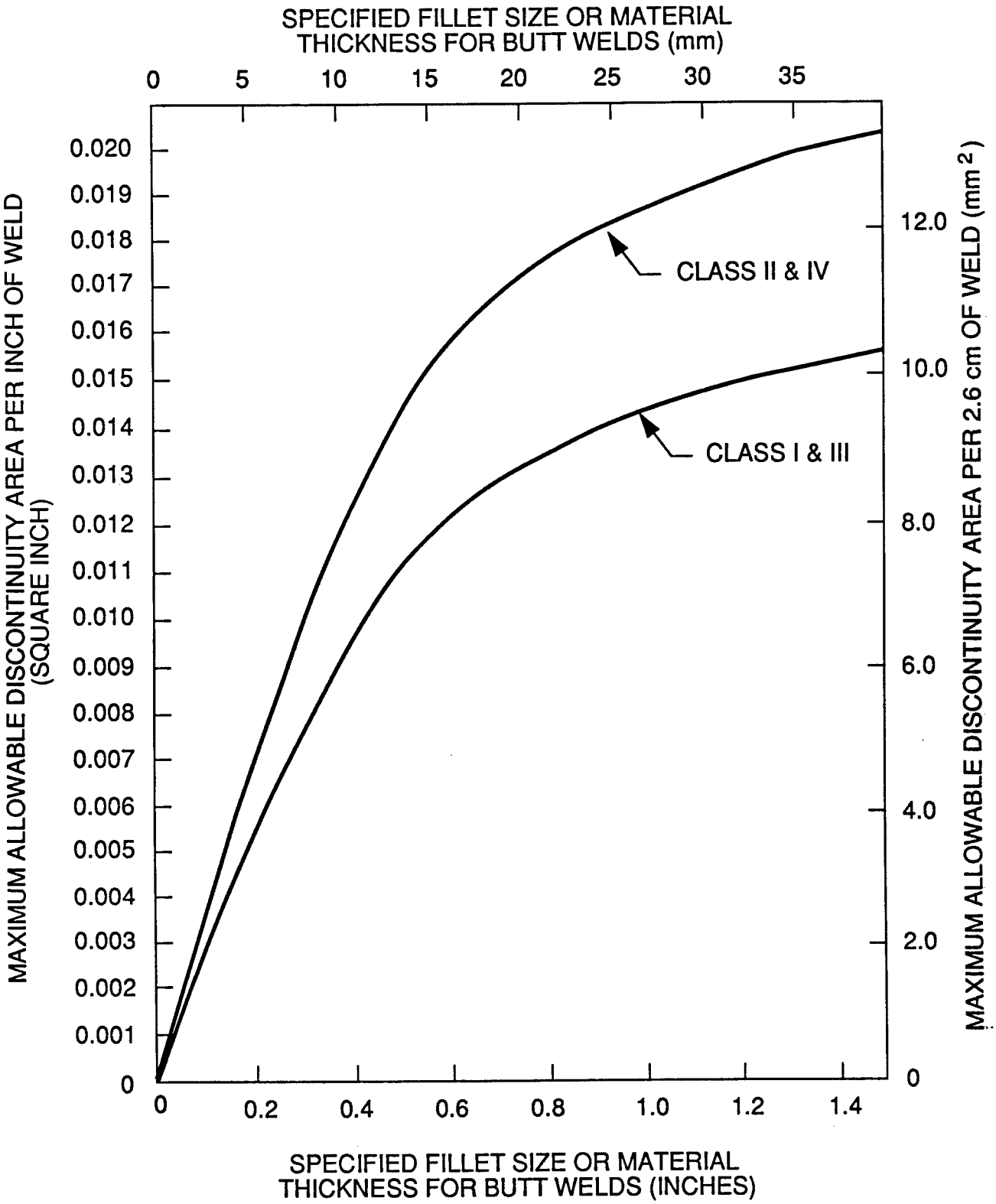
FOR EQUAL-LEG FILLET WELDS, THE FILLET SIZE IS EQUAL TO THE LEG LENGTH OF THE LARGEST INSCRIBED RIGHT ISOSCELES TRIANGLE.

FOR UNEQUAL-LEG FILLET WELDS, THE LEG LENGTHS OF THE LARGEST RIGHT TRIANGLE WHICH CAN BE INSCRIBED WITHIN THE FILLET WELD CROSS SECTION. SIZE OF WELD IS A AND B.

FIGURE 8
SIZE OF FILLET WELD



INTERNAL DEFECTS
FIGURE 9



EXTERNAL DISCONTINUITIES
FIGURE 10

Custodian:

NASA - George C. Marshall
Space Flight Center

Preparing Agency:

George C. Marshall Space
Flight Center

MSFC DOCUMENTATION REPOSITORY - DOCUMENT INPUT RECORD

I. GENERAL INFORMATION

1. APPROVED PROJECT:	2. DOCUMENT/ DRAWING NUMBER:	3. CONTROL NUMBER:	4. RELEASE DATE:	5. SUBMITTAL DATE:
	MSFC-SPEC-504 C		03/05/1991	10/27/2002

6. DOCUMENT/DRAWING TITLE:	7. REPORT TYPE:
Welding, Aluminum Alloys	Specification

8. CONTRACT NUMBER / PERFORMING ACTIVITY:	9. DRD NUMBER:	10. DPD / DRL / IDRD NUMBER:

11. DISPOSITION AUTHORITY (Check One):	12. SUBMITTAL AUTHORITY:	13. RELEASING AUTHORITY:
☒ Official Record - NRRS 8/12/A ☒ Reference Copy - NRRS 8/5/A/3 (destroy when no longer needed)		MB Cook

14. SPECIAL INSTRUCTIONS:

15. CONTRACTOR/SUBMITTING ORGANIZATION, ADDRESS AND PHONE NUMBER:	16. ORIGINATING NASA CENTER: Marshall Space Flight Center 17. OFFICE OF PRIMARY RESPONSIBILITY: ED33

18. PROGRAMMATIC CODE (5 DIGITS):	19. NUMBER OF PAGES:

II. ENGINEERING DRAWINGS

20. REVISION:	21. ENGINEERING ORDER:	22. PARTS LIST:	23. CCBD:

III. REPORTS, SPECIFICATIONS, ETC.

24. REVISION:	25. CHANGE:	26. VOLUME:	27. BOOK:	28. PART:	29. SECTION:
C					

30. ISSUE:	31. ANNEX:	32. SCN:	33. DCN:	34. AMENDMENT:

35. APPENDIX:	36. ADDENDUM:	37. CCBD:	38. CODE ID:	39. IRN:

IV. EXPORT AND DISTRIBUTION RESTRICTIONS

- ☐ Privacy Act (see MWI 1382.1)
- ☐ Proprietary (see MPD 2210.1)
- ☐ Patent (see MPG 2220.1)
- ☐ ITAR (see MPG 2220.1)
- ☐ EAR (see MPG 2220.1)
- ☐ Other ACI (see NPG 1620.1 and MPG 1600.1) _____
- ☒ No statutory or institutional restrictions applicable -- material may be electronically distributed to user in the NASA domain

V. ORIGINATING ORGANIZATION APPROVAL

40. ORG. CODE:	41. PHONE NUMBER:	42. NAME:	43. SIGNATURE/DATE:
ED33	4-2705	Carolyn Russell	W.R. Lamwell for 10/15/03

VI. TO BE COMPLETED BY MSFC DOCUMENTATION REPOSITORY

44. RECEIVED BY:	45. DATE RECEIVED:	46. WORK ORDER:
Tammy Wise	10-29-03	